ENGINEERING CASE LIBRARY

ECL 226

# THE TROUBLED TRUSS

A truss for holding traffic signs and spanning a heavily traveled Freeway was knocked down by a dump truck being used in repair work. The broken truss was removed from the highway as soon as possible. The question now is a matter of what should be done in terms of replacement or repair.



Appreciation is expressed to Reliance Insurance Company of Detroit, Michigan, for extending the courtesy of use of its files.

THE TROUBLED TRUSS

Part A

# Truck Driver Splits Sign, Closes Lodge

Traffic was jammed on the northbound Lodge Freeway from downtown Detroit to the Davison Thursday afternoon when a dump truck driver unloading gravel knocked down a 60-foot-long overhead freeway sign with his raised truck bed.

Detroit police closed the northbound freeway from 3:30 to 4 p.m. to enable Wayne County Road Commission repair crews to get equipment to the scene and clear the freeway.

Police said Charles Hamlet, 37, of Milford, a truck driver for Kensington Corp. of Novi, was unloading the gravel about 2:05 p.m. at the Davison exit of the freeway for use in repair work there.

The rising truck bed hit the overhead sign and broke it in two. One piece fell on the freeway and the other on the roof of the truck cab. The fallen sign blocked off traffic in all but one lane of the northbound freeway.

No one was hurt.

Police ticketed Hamlet for careless driving.

DETROIT FREE PRESS Friday, Oct. 10, '75 9-A

## Observations on General Structural Arrangement

On Friday, 24 October 1975, I viewed the various portions of this structure and the highway sign. Some of the sections were at the scene (Lodge & Davison Freeways) and some were in the Wayne Salvage Yard (Wayne County Road Commission) in Wayne, Michigan. The general configuration of the supporting structure conforms to the Michigan State Highway Department specifications for aluminum trusses (S6.10) as shown in Exhibit 1. The specific structure involved has four sections in the box truss as indicated schematically in Exhibit 2.

One of these sections, (C), is substantially shorter than the other three, being approximately one-third the length of the others which are approximately the same length. An end of a section which mates with an adjoining section has a flange welded to each of the chord members (4 in each box truss section). The junction is made by bolting the flanges from each section together.

The outboard ends of the assembled truss are supported on seats (a shelf-like arrangement) welded to the vertical columns. There are two seats at each end, one seat on each of the two columns. In addition, chord members are held firmly in place against the seats and/or columns, as appropriate, by U-bolts.

## Observations of Damages

The vertical support columns and seats at the west end (median end) of the truss are undamaged. The vertical support columns at the east end (shoulder end) have both seats broken and a horizontal brace member immediately below the seats is missing (Exhibit 3). No other damage is immediately obvious.

The outboard ends of sections A and D have creases across two of the chord members in each section. A segment of the broken seat from the east column is still attached to the chord member by the U-bolt (Exhibit 5). It appears that as the box truss fell from its normal operating position, the loading was such as to cause these creases across the bottom chord members.

Section A has creases in the bottom chord members as noted (Exhibit 2). Two brace members are separated from the chord member at the end (vertical support end). This separation is through the weld between these two members and the chord. There is no other immediately obvious damage.

Section B appears to be the section which was hit by the truck. There is a dent on one side of one of the chord members, in about the middle of section B. Three brace (web) members are missing and two other web members have broken or cracked welds (Exhibits 7 and 8). These are in the immediate vicinity of the apparent impact region. The junction between sections A and B failed by failure of the bolts holding the flanges together.

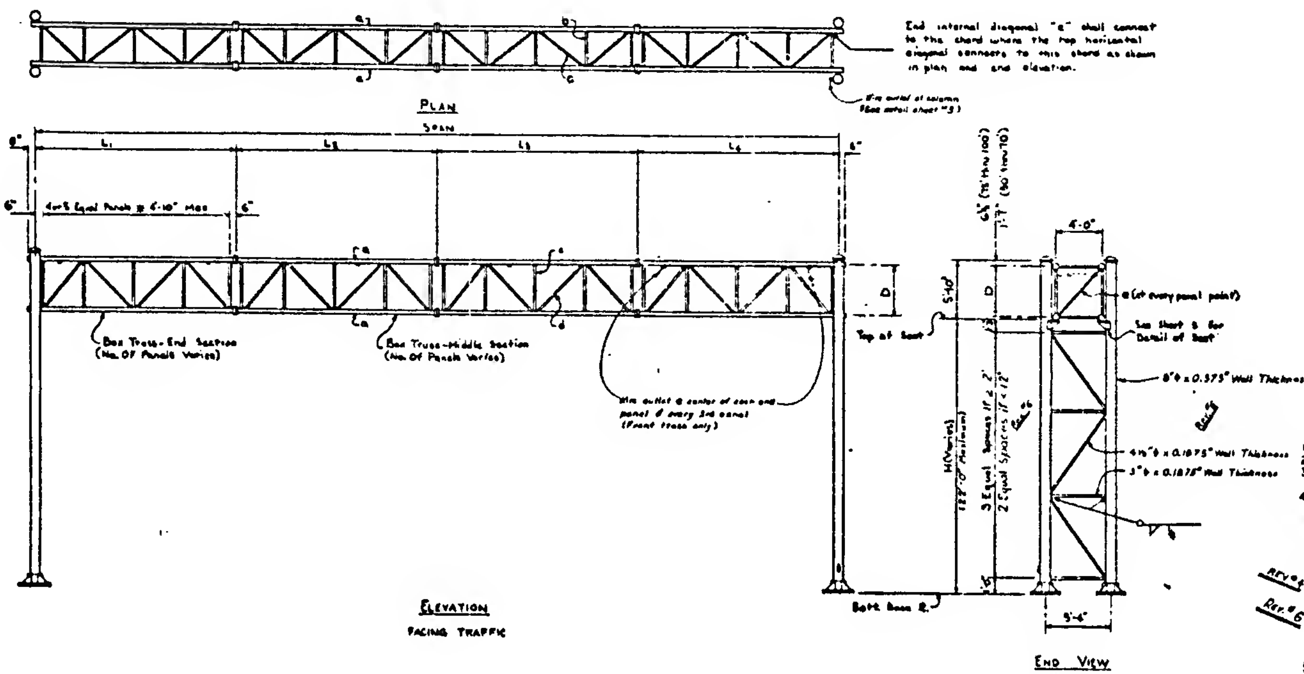
The junction between sections B and C failed by separation of flanges from chord members. The chord member is a tube which has the end inserted into the flange with the flange and chord then welded together on both sides of the flange. Failure of the junction between sections B and C thus involved failure of both welds between chord and flange of all four chord members of the truss (Exhibits 6 and 9). Other than failure at the flanges, there is no other immediately obvious damage to section C.

The junction between sections C and D failed by failure of the bolts holding the flanges together. Other than the creases in the outboard ends of the bottom chord members of section D, there is no immediately obvious damage. Portions of some bolts are shown in Exhibit 10.

The segments of the sign itself which were at the Wayne Salvage Yard appear to be essentially undamaged and presumably can be placed back in normal service with no repairs. One segment of the sign was located at the scene of the accident (Exhibit 4). This segment sustained some damage. The sign was made from a series of extrusions which were joined together. There were some small bends in some of the extruded sections. Two of the extruded sections were partially separated at one end through failure of a few mechanical fasteners. One extrusion was punctured and a small portion along one side of the puncture was bent out of position (Exhibit 4).

Now what?

Obviously, some action is necessary relative to the sign and its supporting structure. At the time of the accident, the highway was cleared. Now the sign must be put up again. Assume you are the member of the Highway Department charged with getting the job done. Will you discard the whole structure and replace it with a new one? Will you have this one repaired and put back into place? Just what action will you take?




**Notes:**

1 All columns and chord members shall be aluminum alloy 6061-T6.
2 All web members shall be aluminum alloy 6063-T6.
3 Connections shall be welded with filler alloy 5556.

4. The design of this structure is based on the American Association of State Highway Officials Specifications for the Design and Construction of Structural Supports for Highway Signs. (1961 Edition)
Sign Area ≤ 300 sq. ft. max. (Type B)
Max. projection of sign beyond chord is 4 ft.

Rev. #4 Design based on a wind load of 30 psf. on sign area.

Rev. #6 All U-Bolts and other hardware fasteners shall be stainless steel - ASTM A 320, Grade B8; AISI Type 304. All other connecting bolts shall be aluminum alloy 2024-T4.

5 See std. plan S9.10 for sign connection.

**TRUSS SCHEDULE**

| SPAN | L1 | L2 | L3 | L4 | D | a | b | c | d | e* | Estimated Weight (lbs/ft) | Camber** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50'-0" | 25'-0" | | | 25'-0" | 4'-0" | 6"Φ x .1875 Wall Thick | 2"Φ x .125 Wall Thick. | 3"Φ x .1875 Wall Thick. | 2"Φ x .125 Wall Thick. | 2"Φ x .125 Wall Thick. | 30 | ½" |
| 55'-0" | 20'-0" | 15'-0" | | 20'-0" | do | do | do | do | do | do | do | 1" |
| 60'-0" | 20'-0" | 20'-0" | | 20'-0" | do | do | do | do | do | do | do | 1⅛" |
| 65'-0" | 20'-0" | 25'-0" | | 20'-0" | do | do | do | do | do | do | do | 1¼" |
| 70'-0" | 25'-0" | 20'-0" | | 25'-0" | 4'-0" | 6"Φ x .1875 Wall Thick | do | 3"Φ x .1875 Wall Thick | do | 2"Φ x .125 Wall Thick. | 30 | 1½" |
| 75'-0" | 25'-0" | 25'-0" | | 25'-0" | 5'-0" | 7"Φ x .1875 Wall Thick | do | 3½"Φ x .1875 Wall Thick | do | 2"Φ x .125 Wall Thick | 31 | 1½" |
| 80'-0" | 20'-0" | 20'-0" | 20'-0" | 20'-0" | do | do | do | do | do | do | do | 1½" |
| 85'-0" | 20'-0" | 25'-0" | 20'-0" | 20'-0" | do | do | do | do | do | do | do | 1¾" |
| 90'-0" | 20'-0" | 25'-0" | 25'-0" | 20'-0" | do | do | do | do | do | do | do | 2⅛" |
| 95'-0" | 25'-0" | 20'-0" | 25'-0" | 25'-0" | do | do | do | do | do | do | do | 2¼" |
| 100'-0" | 25'-0" | 25'-0" | 25'-0" | 25'-0" | 5'-0" | 7"Φ x .1875 Wall Thick | 2"Φ x .125 Wall Thick | 3½"Φ x .1875 Wall Thick | 2"Φ x .125 Wall Thick. | 2"Φ x .125 Wall Thick | 31 | 2½" |

* For transverse diagonals at panels adjacent to columns use 3½"Φ x .1875

** Ordinate at center of assembled truss prior to dead load deflection. Allowable camber tolerance for truss is ± 15%

Work this sheet with sheets 3 & 4

MICHIGAN STATE HIGHWAY DEPARTMENT

ALUMINUM TRUSS
TYPE B

S6 10

6. U-Bolt Information added. 10-67 DP

# EXHIBIT 1

Notes:

1. All columns and chord members shall be aluminum alloy 6061-T6.
2. All web members shall be aluminum alloy 6063-T6
3. Connections shall be welded with filler alloy 5356.
4. The design of this structure is based on the American Association of State Highway Officials' Specifications for the Design and Construction of Structural Supports for Highway Signs. (1961 Edition)

   Sign Area = 300 sq. ft. max. (Type B)
   Max. projection of sign beyond chord is 4 ft.

   Design based on a wind load of 35 psf. on sign area.
   All U-Bolts and accompanying washers shall be stainless steel - ASTM A 320, Grade BB (AISI Type 304). All other connecting bolts shall be aluminum alloy 2024-T4.
5. See std. plan S9.10 for sign connection.

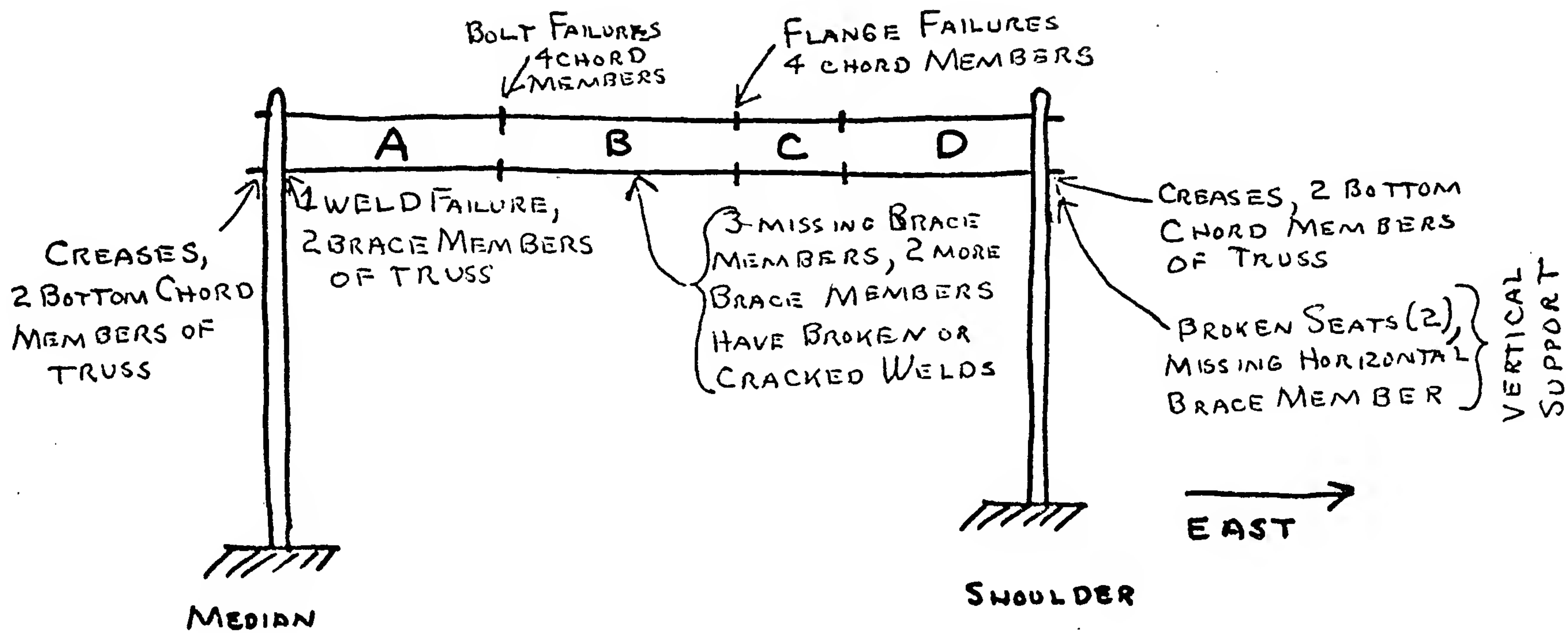



EXHIBIT 2 – TRUSS & VERTICAL SUPPORTS AT LODGE & DAVISON FREEWAYS, DETROIT, SHOWING MAJOR ITEMS OF DAMAGE (SCHEMATIC)

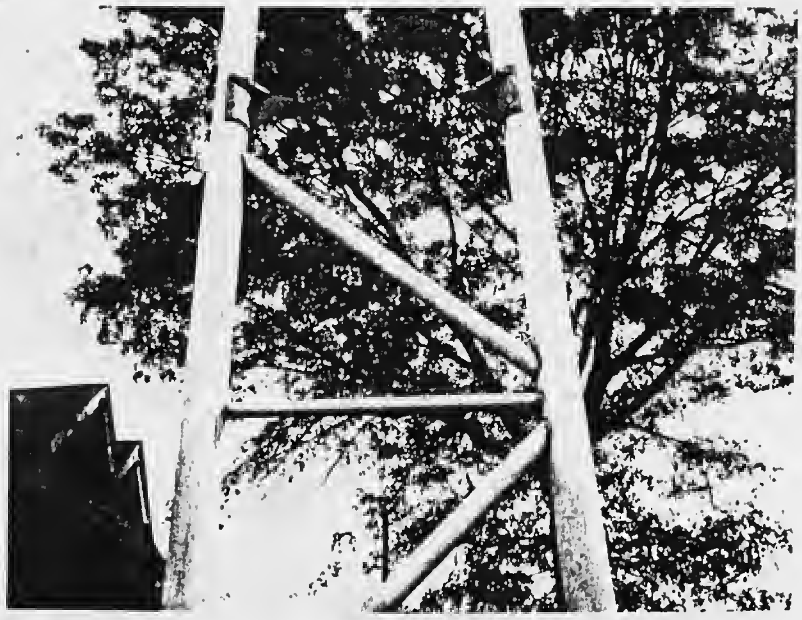


Exhibit 3 Vertical support at east end of structure showing broken support seats and horizontal bar missing just below the support seats.

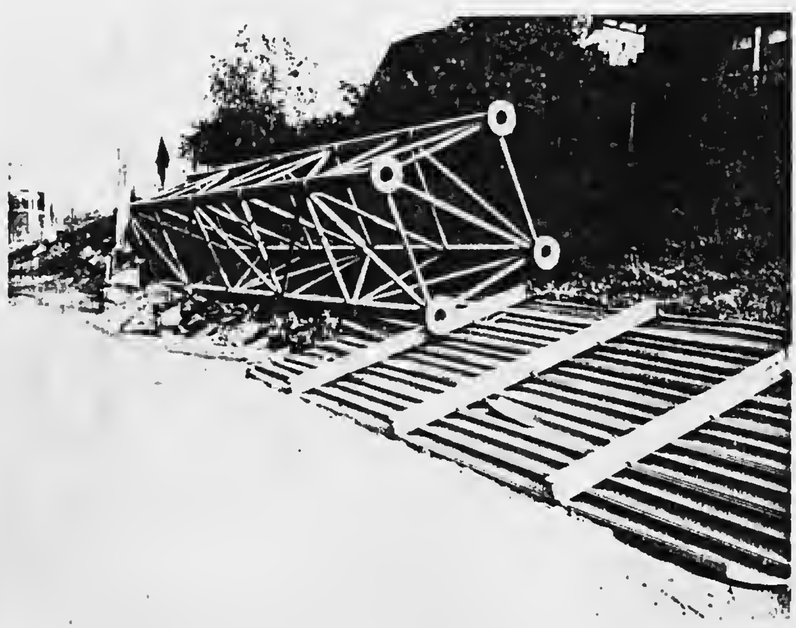


Exhibit 4 West end of truss (Section A, Exhibit 2) with damaged portion of sign.

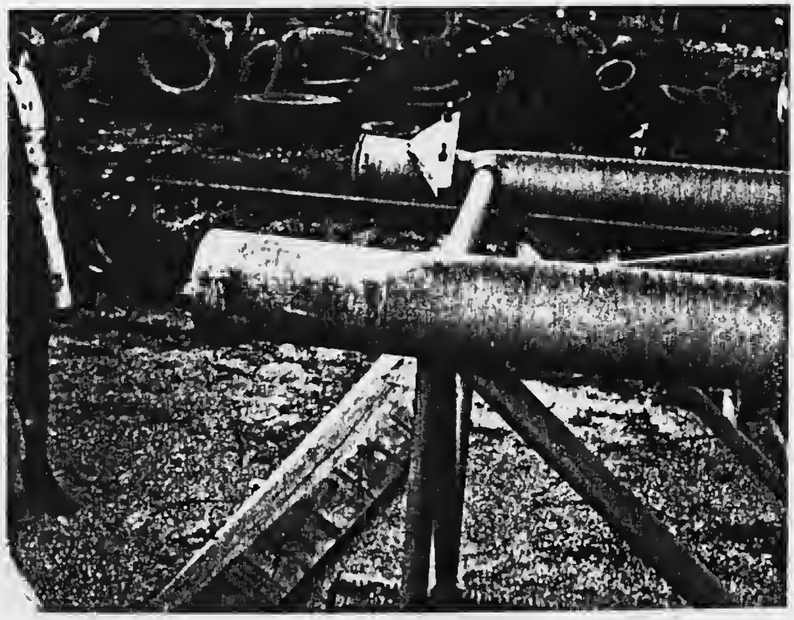


Exhibit 5 East end of Section D (Exhibit 2) showing broken portion of support seat still attached by a U-bolt.

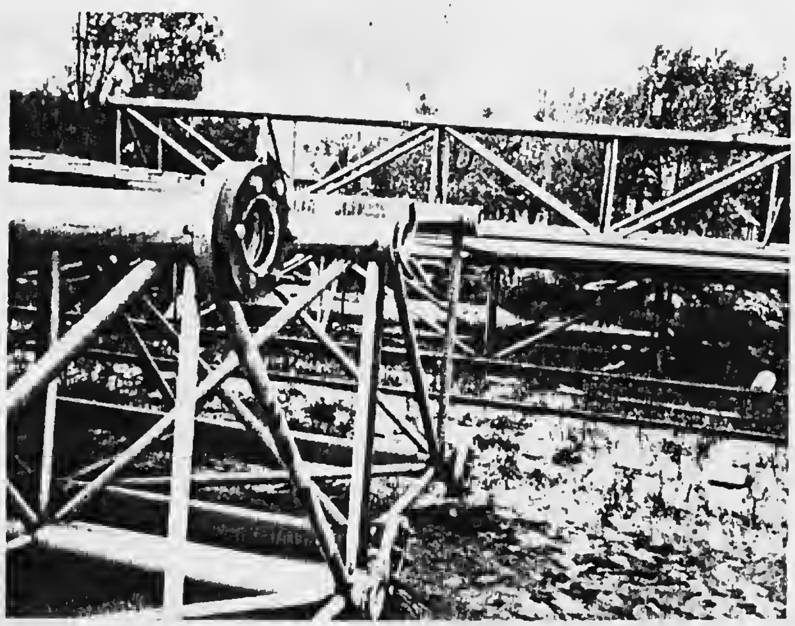


Exhibit 6 Mating ends of Sections B and C (Exhibit 2) showing failure of junctions between chord member and flanges.

Exhibit 7 Section of truss showing complete faulure through the welds between the main chord member and three bracing (web) members.

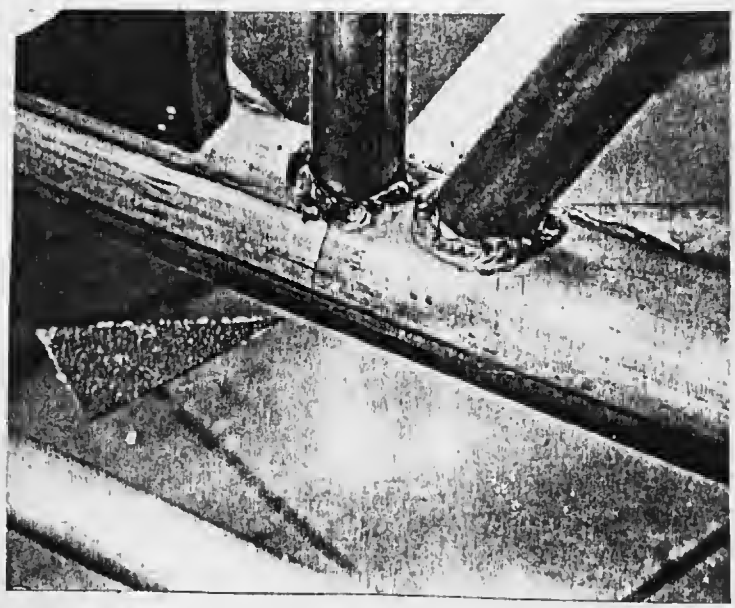
Exhibit 8 Section of box truss showing a crack in the weld between main chord member and web member. This is the other end of the bracing member shown in Exhibit 7.

The Troubled Truss

Supplement --- Part A

Consider a similar truss but erected at a different time in a different place. In this situation, the truss had been in service for some months when men doing some work on the truss noted a crack as shown in the left hand photograph. Further examination revealed the cracks noted in the right hand photograph. This obviously caused considerable concern. A careful examination of the rest of the truss and the general circumstances gave no indication of any specific reason for the cracks.

Consider yourself in the role of the highway engineer who must consider the possibility that other trusses may have the same problem. How would you determine the cause of the cracks? What action would you take to "cure" the problem?



# THE TROUBLED TRUSS

## Part B

### Comments

The information on Exhibit 1 indicates the major members (chord and column members) are aluminum alloy 6061-T6, the web members are aluminum alloy 6063-T6, and the filler metal used in welding is aluminum 5356. Both 6061 and 6063 are heat treatable by precipitation hardening.

The alloys indicated by the specifications are reasonable and fairly standard choices for the intended application. The general appearance of the welds throughout the structure was good and indicates good welding procedures in assembly. (The fact that some joints failed through the welds and some failed by breaking of the bolts indicates a "balanced" execution of the design.) The two alloys, 6061 and 6063, were specified in a heat treated condition (T6). Welding with the specified filler alloy, 5356, which normally does not have any post weld heat treatment, automatically gives a structure which is somewhat weaker in the vicinity of the weld than in the body of the members. It appears that this was accounted for in the design and assembly of the truss.

The preliminary examination conducted on 24 October 1975 indicates that the truss sections are still in generally good condition and can be repaired rather than discarded.

It appears that all the members which failed in welds failed from overloading caused by the accident and not because of faulty welds in the assembly.

### Opinion

It is my opinion that the sign supports involved can be reused after some repair. All failures through welds can be repaired by rewelding where members are still present. Some replacement members will be needed. These can be obtained and welded into the appropriate positions. The weld failures at flanges can be repaired either by rewelding of the failed flanges or by welding replacement flanges in the required locations. Rewelding will have no detrimental effects on the structure. It has been shown (*) that rewelding of 6061-T6 with filler alloy 5356 (and no subsequent thermal treatment) has no significant affect on tensile

*F. G. Nelson, "Effect of Repeated Repair Welding of Two Aluminum Alloys", Welding Journal, 40, Res. Supplement, No. 4, pp 166s, April 1961.

properties or the width of the heat-affected zone with up to 6 rewelds. In other words, rewelding gives no further change from the weakening by the first weld as noted above.

In the case of the vertical support column (east end), the broken segments of the seats can be removed and replacements welded in place. A replacement member for the missing horizontal member can be welded in position.

It can be argued that the segment of the sign which is damaged should be replaced. It is my opinion that, while this is possible, it would also be possible to straighten out the dents and bends and to put new mechanical fasteners between adjoining extruded segments as required. The punctured and bent segment can be flattened back into position with a backing strip fastened on the back of the sign.

It is my opinion that the presence of the creases at the support positions at each end of the bottom chord members of the box truss will have no significant effect on the strength of the box truss and thus will have no adverse effect if the box truss is repaired as suggested above and replaced in position, with the creases still present.

Cautions to be Noted

If repair is accomplished as recommended above, it would be advisable to make a careful visual inspection (preferably with a hand magnifying glass) of all existing welds to make sure there are no cracks in other welds. In different words, each existing weld should be carefully examined to be sure that <u>all</u> failed and cracked welds are repaired. In the case of any weld in which there is doubt after visual inspection, it would be appropriate to conduct a dye penetrant inspection.

In making repair welds in the aluminum alloys in this structure, qualified welders must be used. While these aluminum alloys are not too difficult to weld, the techniques are different from those used to weld many steels. Thus a welder who may be excellent in welding steel may not be qualified to weld aluminum alloys. If there is a question of weld quality, visual and/or dye penetrant inspection can be used after welding.

Summary Opinion

After viewing the damage to the structure supports involved, it is my opinion that all the damage can be repaired with relatively little replacement involved. After repair, the structure can be returned to service and be expected to perform as designed, provided the repair welds are properly executed. Repair of the structures would be very much less expensive than replacement of the structure.

# The Troubled Truss

## Supplement --- Part B

After extensive "soul searching" and/or "head scratching" following careful examination of the truss and the circumstances, observers were sent out to watch the truss. This sounds somewhat like a move of desperation but it was believed that there might be something which had been overlooked. As it developed, after some period, an observer heard the truss almost literally "singing in the wind." The highway at that point was in a valley and the wind channeled through. It was concluded that the truss was in resonance (or close to it) and thus failure was fatigue from relatively low-cycle, high amplitude loading. The truss was redesigned for a much higher natural frequency. The redesigned truss functioned without difficulty.

The Troubled Truss Instructor's Note

This case has at least two foci: the strength of the truss and supports; and the choice of alloys, welding procedures and the question of rewelding. Obviously, both can be treated. Perhaps this case is of particular interest to civil engineers but it certainly has broader application.

One possible approach to use of this case is to pose a series of questions such as: What is the truss made from? What specific alloy (or alloys) within that base metal system are used? What treatments are possible for these alloys? (Since the alloys of concern are aluminum 6061-T6 and 6063-T6, the details of precipitation hardening can be explored.) Can these alloys be welded? (Obviously!) Can these alloys be rewelded? If rewelded, what is the strength and serviceability of the structure (or welds) for continued use? If welded, is further heat treatment needed? And so on. The question of the effect of the "creases" at the ends of the chord members on the strength and serviceability may also be of interest. There is also a question of costs.

This case provides a good opportunity for getting the students into the library to seek information. Reference is made in Part B to a paper by F. G. Nelson in the Welding Journal. While one certainly can go directly to the Welding Journal and other possible sources, probably the most fruitful source (and one which covers all the metallurgical aspects) is the three volume set on "Aluminum", edited by Kent Van Horn and published by the American Society for Metals in 1969.

The difference in length of the four sections was the result of adding one lane of pavement. In that phase, the truss was taken down, separated, and a short section added to give the proper total length.

The supplement is the case of a truss designed and built much earlier than the truss in Detroit. It provides an additional dimension, i.e., vibration, which seems to be overlooked from time to time. Although no dimensions are given (the only information available was the statement and the two photographs), it can provide an interesting exercise.